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1.2 USE OF AN EYE-SAFE, PORTABLE LIDAR FOR REMOTE WILDLAND FIRE AND SMOKE DETECTION

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1. INTRODUCTION

During periods of drought when surface water supplies are severely limited, wildland forest fires tend to become more frequent and often can grow into major fires that threaten valuable timber, real estate, and even human lives. Fire-fighting crews are critically dependent upon accurate and timely weather data to help ensure that individuals are not inadvertently exposed to dangerous conditions and to enhance normal fire-fighting activities. To that end, the use of an eye-safe, portable lidar for remote wildland fire and smoke detection is described. By using an infrared, eye-safe wavelength near 1.5 µm, remote detection of smoke, flame fronts, and even air flow can be accomplished. Field tests of this technology have shown that actual reflections (signal returns) can be used to diagnose the condition of a fire and its tendency over time. Velocity detection distances can be reliably made in the range of 100's of meters with even beyond 1 km possible. In addition, movements of smoke particles can be used to infer air motions within and adjacent to smoke plumes at smaller scales, like flame fronts, to even whole fire plumes that exit the actual fire zone.

2. LIDAR DEVELOPMENT

Lidar, in this sense is an acronym (for **Li**ght **D**etection **a**nd **R**anging) that describes a unique radar type of instrument that uses light beams to detect not only solid objects, but particulates, hydrosols, environmental contaminants, etc. at locations remote to the instrument itself. In this sense, it is a remote sensing technology that depends on active projection of a sampling light beam. Lidar systems have existed for more than 30 years in a variety manifestations and sensor implementations. Currently, the term "lidar" is associated principally with a laser based optical system whose principal task is the measurement of range, velocity, acceleration and intensity (e.g. imaging and chemical species detection) of a particular object or element (e.g. an environmental contaminant).

Historically, with regard to active fiber lidar sensors and systems, development of fiber lidars dates from the early 1990s at a variety of institutions, particularly those interested in optical air data for aircraft. The limiting factor in many programs was the lack of suitable source power and a dearth of the required fiber components. Today, thanks in large part to developments in the telecommunications industry, active fibers are available in a wide range of wavelengths: from 1.06 µm with Ytterbium (Yb) doping to beyond 2 µm with Erbium (Er) and Raman laser systems. Of interest in many of these programs, is the fact that the fiber oscillators used in the lidar achieved laser line widths of approximately 200 Hz, which defines a theoretical lower Doppler velocity limit of 0.0001 m/s.

Figure 1 shows a basic schematic for a fiber optic lidar. As with all lidars, the optical power is the dominant limiting factor regarding sensing capabilities. In this case, the ability to detect particles reflective in the 1.5-µm range is key to obtaining wind or smoke data. And, as the distance to the target increases, the sample volume increases; thus, more particles are available for detection. The available optical source power dictates the distance (i.e., range) from which adequate signals (detection) can be obtained.

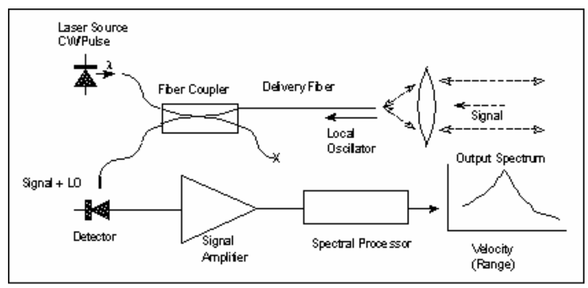

Figure 1. Generic schematic of a fiber lidar

Figure 2 (next page) shows a fiber optic lidar prototype that utilizes a low-power, multi-functional, Erbium-Doped Fiber Amplifier (EDFA) system in the 1.55-µm wavelength band, due to the eye-safe nature of the lidar emission and the ability to configure the emission spectrum to the high transmission regions of the atmospheric spectrum. These master oscillator/power amplifier (MOPA) configurations operating in coherent and incoherent modes, using a wide range of wavelength combinations, pulse widths, pulse repetition frequencies (PRF), and continuous wave (CW) formats, offer broad flexibility for obtaining range, velocity, and Doppler phase shift information.

3. SMOKE TESTS

The lidar was used to examine the velocity structures in smoke. In the initial series of reported tests, smoke aerosols from burning leaf matter are investigated for the turbulence spreading associated with thermal up-welling. This methodology generates data consistent with a variety of meteorological phenomena (e.g. cloud thermal motion, light clear air boundary flows, etc.) and is therefore of

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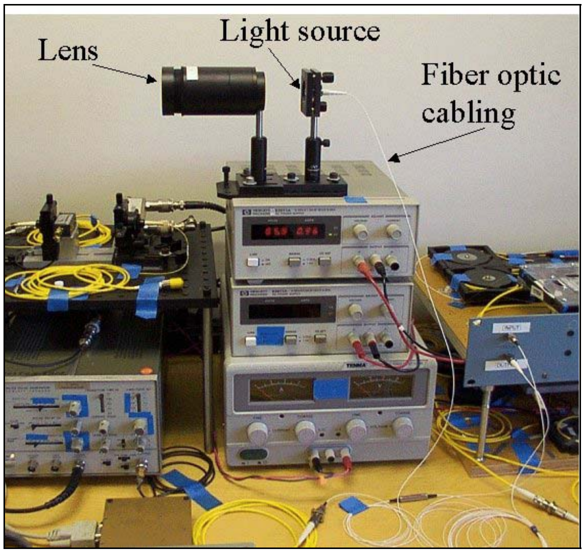

Figure 2 Fiber lidar prototype

significant interest in determining the signal parameters and processing requirements incipient in ongoing programs. It is also of interest in that the structure of smoke velocity from such fires is indicative of burn rate, and this technique may be used to remotely interrogate forest fires for monitoring rate of burn or for determining the movement of the fire front itself. A burn barrel located several meters away from lidar was filled with dried and wet leaves and ignited to generate a fast fire phase followed by denser periods of smoke. The lidar was located 4.25m above the barrel and beam penetration is at a 30 degree axis to the vertical to preserve as much of the vertical fire axis velocity component as possible given the test scenario. The prevailing varied between 1.5 ms^{-1} and 3 ms^{-1}.

Consequently, added spreading of the smoke velocity is to be expected in a manner similar to that which would be encountered in the free atmosphere when measuring returns from other aerosols.

In Figure 3 below, the velocity of the smoke in the line of the laser beam is recorded by the lidar. In figure 4, the velocity is tracked together with the intensity to illustrate the ability of the lidar to detect smoke intensity. Both figures show the ability to infer burn rate from the data by detecting and measuring the motions and density of smoke particles in the plume. An algorithm that combines this data could be developed and tested for wildland fires.

Figure 5 shows another example of remote smoke detection with the prototype lidar. The relative peaks in the signal intensity monitored over time and distance allow for an indirect characterization of the fire through observations of the smoke particles emanating from the fire. Note that the plume center is over 650 m from the lidar. In this case, the user of the lidar was situated well away from the fire in a safe and remote location.

4. SUMMARY

The data from these tests show several promising aspects. Smoke particles and particle density can be detected remotely at ranges up to 0.5km with longer distances possible. Upward motions of smoke plumes (upwelling) can be measured and this data can be used to possibly infer fire intensity. The lidar used to make these measurements can be made portable for field deployment. These capabilities make this lidar a useful tool to detect critical characteristics of wildland fires for fire-fighting crews.

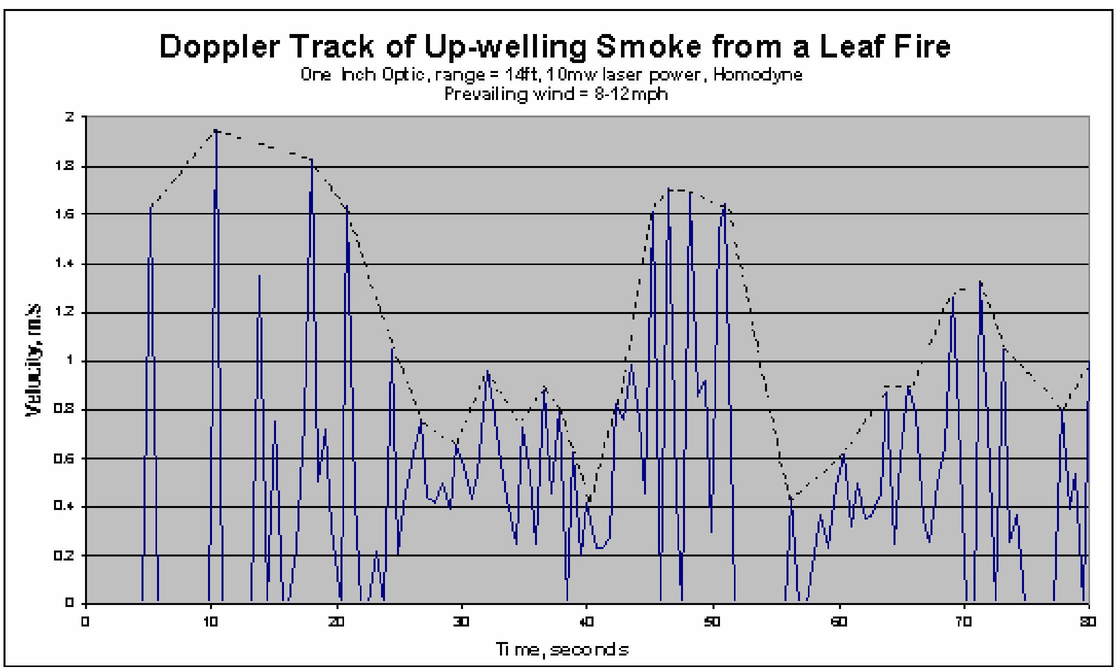

Figure 3 Time sequence of up-welling smoke within the measured velocity “envelope”

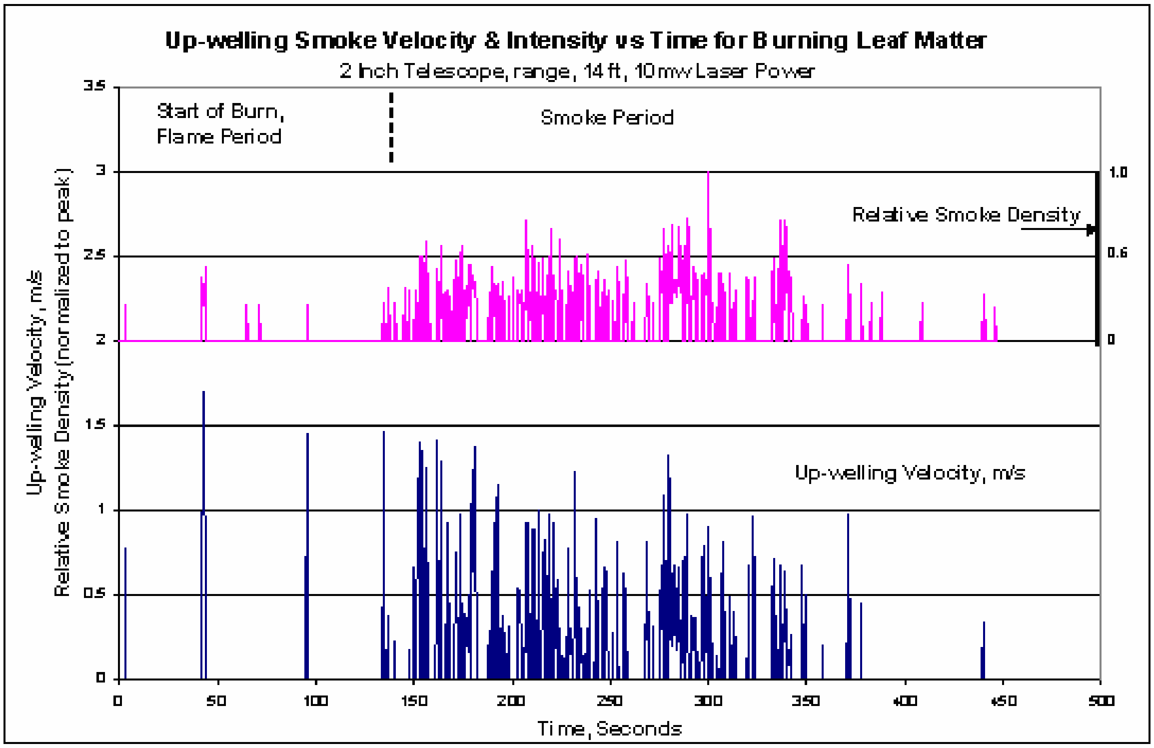

Figure 4 Time sequence of up-welling velocity and intensity of the velocity. Variations are due to changes in the prevailing wind.

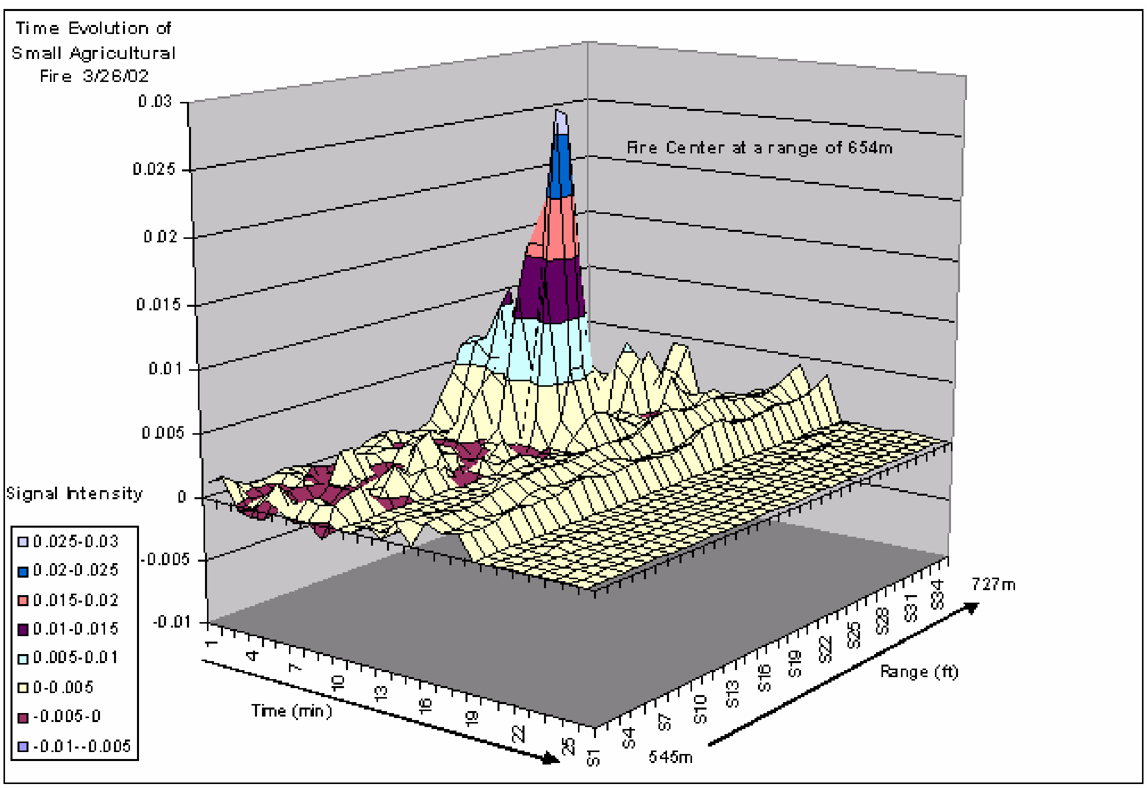

Figure 5 Lidar data observed during a small fire in a field. The signal intensity increases as the smoke plume thickens.